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# CALIBRATION TESTS OF A490 HIGH STRENGTH BOLTS



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see inside for series

UNIVERSITY OF ILLINOIS
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# CALIBRATION TESTS

# OF

# A490 HIGH-STRENGTH BOLTS


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A Report of an Investigation Conducted

by

THE UNIVERSITY OF ILLINOIS ENGINEERING EXPERIMENT STATION

in cooperation with

~~The Research Council on~~ Riveted ~~and~~ + Bolted Structural Joints PR MAR 64

The Illinois Division of Highways
(Project IHR-5) PROJ 5

and

The Department of Commerce -- Bureau of Public Roads


Department of Civil Engineering
University of Illinois
Urbana, Illinois


March, 1964

# CALIBRATION TESTS OF A490 HIGH-STRENGTH BOLTS

## SYNOPSIS

Over fifty calibration tests on 7/8 in. diameter ASTM A490 high-strength bolts were conducted. Data on bolt tension, elongation, turns of nut, and general behavior were analyzed. Comparisons were made of bolt behavior when torqued in a commercial load cell and in a solid steel block: it was found that a significant difference exists between these two conditions. The general characteristics of the A490 high-strength bolt appear to be similar to those of the familiar A325 bolt, but the physical properties of the new bolt will provide greater fastener strength and joint clamping.

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# CALIBRATION TESTS OF A490 HIGH-STRENGTH BOLTS

## I. INTRODUCTION

### 1. Scope of Investigation

This investigation was approved by the Research Council on Riveted and Bolted Structural Joints in March, 1963, in order to provide the additional data necessary for possible revisions (in 1964) to the specifications of the Council. Although the ASTM A354 grade ~~BD~~ BC bolt has been permitted in the 1961 and 1963 editions of the specifications of the American Institute of Steel Construction, it was found that the A354 grade BD bolt offered greater strength at very small additional cost and might prove more economical in structures. The American Society for Testing and Materials acknowledged the need for a structural bolt of higher strength by developing a specification for a heavy structural bolt, comparable dimensionally to the ASTM A325 fastener but with material properties similar to the ASTM A354 grade BD bolt. This new bolt, ASTM A490 (Tent.), "Quenched and Tempered Alloy Steel Bolts for Structural Steel Joints, Including Suitable Nuts and Plain Hardened Washers," should be approved by ASTM in March, 1964. With the A490 bolt specification approval, a need arises for the information necessary to permit revisions in the specifications of the Research Council and of the American Institute of Steel Construction, in order that designers may take advantage of the new bolt.

A second purpose for this study was to determine whether different testing procedures employed at various laboratories would contribute significantly to experimental scatter. By having the University of Illinois and Lehigh University conduct the testing in duplicate, this possible variable could be checked. All bolts, nuts, and washers were supplied by a well-known manufacturer in sufficient quantities from the same lots, to Lehigh University.

There the bolts were identified and selected at random so that Illinois would receive half of each lot. All special equipment used for testing was supplied by the respective university. Separate reports are being written by the staff of both universities, describing their own techniques and results. A combined report incorporating the work done at both laboratories will be prepared for possible publication in the near future.

2. Acknowledgments

The tests reported herein were part of investigations resulting from a cooperative agreement between the Engineering Experiment Station of the University of Illinois, the Research Council on Riveted and Bolted Structural Joints, the Illinois Division of Highways and the Department of Commerce -- Bureau of Public Roads. The tests, a part of the structural research program of the Department of Civil Engineering, of which Dr. N. M. Newmark is Head, were conducted by E. W. J. Troup, Research Assistant, working directly with E. Chesson, Jr., Associate Professor of Civil Engineering, and under the general supervision of W. H. Munse, Professor of Civil Engineering.

The work of this program was planned in cooperation with Committee 15 of the Research Council on Riveted and Bolted Structural Joints and was supported by the Council. The members of the Committee (1964) are as follows:

T. R. Higgins, Chairman
L. S. Beedle
R. B. Belford
E. L. Erickson
F. E. Graves
G. S. Vincent
W. H. Munse
E. J. Ruble
A. Schwartz, Jr.
T. W. Spilman
D. K. Tarlton
F. H. Dill

Acknowledgment and appreciation are also due the staff at Lehigh University, especially Mr. G. Sterling and Dr. J. W. Fisher for their assistance in forwarding the prepared specimens and for their cooperation as the program was developed.

# II. DESCRIPTION OF TESTS

## 3. Materials and Equipment

Tests were conducted on A490 heavy hexagon head 7/8 in. diameter bolts having lengths under head of 5-1/2 in. and 9-1/2 in. The 5-1/2 in. bolts had 1-1/2 in. of thread produced by rolling between dies, while the 9-1/2 in. bolts had 1-1/2 in. of thread produced by machine cutting. The bolts were received from Lehigh with gage holes drilled in the center of either end, along with a stamped identification number. The threads of the nuts and of the 9-1/2 in. bolts were well-lubricated, but those of the 5-1/2 in. bolts appeared quite dry when received. In every test, one hardened washer was used under the heavy hexagon A194 Grade 2H nut. The washers were noted to have a rather large amount of rough mill scale on both surfaces.

The calibrator used for the torque tests was a Skidmore-Wilhelm Model M, Serial 342, which uses hydraulic pressure for load measurement. This unit was carefully calibrated at intervals during the testing program to insure that the vibrations from pneumatic torquing did not alter the calibration and accuracy. For both lengths of bolts, a rear adaptor was machined to accept the bolt head and to fit the calibrator in order to provide the proper grip with a minimum number of plies or parts in the assembly.

For the tests which were torqued in a solid block, a four inch thick, 4 in. x 4 in. block of A440 steel was drilled and was re-used for every such test. For these tests, as for all others, a hardened washer was used under the nut only.

It was necessary to employ two different multiplying C-frame extensometers for elongation measurements. An extensometer with a 12-1/2 in. maximum gage length was used for the 9-1/2 in. bolts, while one with an

8-1/4 in. maximum gage length was used with the 5-1/2 in. bolts. Both extensometers were carefully calibrated against a super-micrometer before testing, in order to determine accurately the multiplication factors. The multiplication factor for the larger extensometer was 0.218 and for the smaller extensometer it was 0.22. Thus, the actual changes in bolt elongation were magnified approximately four and a half times by these lever-type extensometers. In order to assure consistent elongation readings, in so far as possible, each extensometer was equipped with a counter-balance as shown in Figures 1a and 1b. The counter-balance was attached so as to cause the entire weight of the extensometer and of the counter-balance to be carried by the fixed point. This enabled the highly sensitive, movable point to be influenced solely by the elongation of the bolt, and assured consistently uniform seating of the movable point in the bottom gage hole.

4. Test Variables

The type and number of tests which were conducted are shown in the following table:

| | | | | | |
|---|---|---|---|---|---|
| Length, | in. | 9-1/2 | | 5-1/2 | |
| Total Grip, | in. | 8-1/4 | 8-11/16 | 4-1/8 | 4-9/16 |
| Thread Length in Grip, | in. | 1/8 | 9/16 | 1/8 | 9/16 |
| Direct Tension | | 6 | 5 | 5 | 5 |
| Torqued Tension (Skidmore-Wilhelm) | | 5 | 5 | 5 | 5 |
| Torqued Tension (4 in. Solid Steel Block) | | - | - | 5 | 5 |

It can be seen that the variables included total grip, thread length in the grip, and method of loading. The grip was measured from the underside of the bolt head to the face of the nut in contact with the washer. The thread length under the nut was measured from the beginning of the minimum root diameter of the bolt thread (start of first full thread) to the face of the nut.

5. Test Methods

Observations made before every test were: (1) the actual bolt length (to 1/32 in.); and (2) the number of turns of the nut required to back it off from the stop position to the required grip (this gave some indication of relative fit of nut and bolt threads and served as a check on the measured thread length in the grip). Before testing, the gage holes at the ends of the bolts used to accommodate the extensometer were reamed lightly by a hand-held cold punch, in order to remove dirt and burrs and to "set" the edges of the hole.

The following measurements and observations were made at the termination of the applicable tests:

1) Final bolt length (to 1/32 in.)
2) Amount of nut rotation to failure
3) Rupture load
4) Location and type of failure
5) Ease with which the nut could be turned on the bolt threads after failure (indicating possible strippingof the threads).

6. Direct Tension Tests

The direct tension tests were conducted on a 120 kip* Baldwin hydraulic testing machine, employing special holders having replacable inserts to accommodate various bolt diameters. These are shown in Fig. 1a. Large particles

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* One kip equals 1000 pounds.

of dirt were removed from the 9-1/2 in. bolts with a wire brush to allow easy turning of the nut to the proper grip of the specimen. To attain a 9/16 in. included thread length in the grip with the 9-1/2 in. bolt, the nut had to be brought just flush with the end of the bolt.

For all tests, the bolt was taken up to proof load (55.45 kips) at 5 kip increments, from a 0.6 kip initial load, and elongation readings were taken at each level. A small initial load was desirable in order to keep the bottom holder in place while initial extensometer readings were made. Then the bolt was unloaded to 0.6 kips and measured to determine the residual proof load elongation. The bolt was again taken up to proof load, this time at a constant head speed of 0.02 inches per minute. Then the bolt was tested to failure at a head speed of about 0.05 inches per minute, with load and elongation readings taken at various points until the extensometer ran out of travel, which occurred well after the ultimate load had been reached.

In general, three elongation readings were taken at each loading increment, and they usually fell within a dial range of .001 (or within .0002 in. actual). The average of these three readings was then converted to the actual change in elongation in inches.

The first two direct tension tests of the 5-1/2 in. bolts with the 4-1/8 in. grip exhibited thread stripping failures. Because of this, the remaining tests of the 5-1/2 in. bolts (direct and torqued tension) included a measurement of the bolt and nut thread diameter dimensions to check the fitting tolerance.

7. Torqued Tension Tests - Calibrator

Ten each of the 9-1/2 in. and 5-1/2 in. bolts were torqued in the calibrator. A 7/16 in. thick square "washer" was used at the calibrator face in order to obtain the longer grip. After packing the calibrator to the required grip with the appropriate rear adapter, the bolt and nut were installed to a "finger-tight" position. The nut was then tightened with a hand wrench to 5 kips and then to 10 kips; elongation and nut rotation readings were taken at both loads. From this point, the nut was tightened to failure with a CP612 impact wrench from the "snug" position (10 kips) in 30 degree increments (1/12 turn), with load and elongation data taken at each. The set-up for these tests is shown in Fig. 1b. The same respective extensometers used in the direct tension tests were employed for this group also, except for four of the 5-1/2 in. bolt tests (two each with 1/8 in. and 9/16 in. thread in the grip). The elongation measurements of these four bolts were made with the large extensometer in order to double-check the extensometer response. Rotation was measured by means of a paper rosette divided radially into 30 degree sections and taped to the calibrator face plate.

During the first two torque tests, it was noticed that the hardened washer was turning with the nut. At the conclusion of the second test, the rough surface of the washer had galled the calibrator face plate to such an extent that it was decided to apply "Lubriplate" to the surface of the washer in contact with the nut to decrease the nut-washer friction and to reduce the probability of the washer turning. This procedure was successful and was used on all the remaining torqued tests since torque was not being measured. Bolt and nut thread diameters were measured before testing: however, no bolts failed by thread stripping in the calibrator. A small amount of light utility oil was put into the nut threads of the 5-1/2 in. bolts to minimize the possibility of thread stripping, since these bolts appeared dry. An air pressure of 100 pounds for the pneumatic wrench generally enabled a 30 degree increment to be made in a maximum torquing time of about 5 seconds.

8. <u>Torqued Tension Tests - Solid Block</u>

For this series of tests, the 5-1/2 in. bolts were tightened in the solid block, which was held in a large vise. The nut was brought to a "finger-tight" position, and then tightened to the mean "snug" elongation obtained from the calibrator tests. The nut was torqued to failure and elongation measurements were taken at 30 degree increments. The ~~8~~7/16 in. thick square "washer" was again used in the test set-up to obtain the 4-9/16 in. grip. The position of the extensometer was vertical as shown in Fig. 1b for the test in the calibrator.

## III. RESULTS AND ANALYSIS OF TESTS

### 9. Tabulated Results

The results contained in this report on A490 bolts will serve to supplement those available previously on structural sizes of A354 bolts (Ref. 1, 2, 3). The test data obtained at the University of Illinois have been summarized in Tables 1 and 2. Where possible, these data have been compared with those from Ref. 4 and the excellent agreement in almost every entry is apparent. The mean elongation at ultimate load was the only value which seemed to differ substantially. In the case of the direct tension tests, this may have been the result of the slow rate of loading employed (.02 inches elongation per minute) in the University of Illinois tests. The ultimate (maximum) load held for a relatively long period of time such that the exact time of reading the extensometer was somewhat arbitrary. As for the torqued tension tests, the bolt tension remained at the ultimate load (read to the nearest 0.5 kip) sometimes for as much as one-third of a turn in the calibrator. In these cases, when the same load was recorded over several 30-degree increments, the value at the "middle" increment was taken as the elongation at ultimate load.

### 10. Load-Elongation Relationships

Figures 2 through 8 show the individual test results and the average curves of the load vs. elongation data. Figure 2 shows that the plastic deformations of the 5-1/2 in. bolts occurs beyond the prescribed proof load in direct tension (as required by specifications), while Fig. 3 shows that in torqued tension tests the plastic action begins sooner because of the combined stresses produced by tightening. Figure 4 combines Figures 2 and 3 with curves from Ref. 4, thereby showing in a single plot the similarity of results between the two parallel studies, as well as the effect of different thread lengths in the grip. From these curves it can be seen that in the elastic region, a difference in the thread length in the grip (1/8 in. or 9/16 in.) has little effect. However, the ultimate load for bolts with the shorter thread length in the grip averaged about 5 percent greater than that for bolts with the longer included thread length. Also, there was a noticeable increase in ductility or total elongation observed for the tests conducted with the longer (9/16 in.) thread in the grip, as can be seen from these figures and the tables. Very similar results can be seen in a study of Figures 5 and 6, and also in Fig. 7, which combines the average curves for 9-1/2 in. bolts from Figures 5 and 6 with data from Ref. 4. For these longer bolts, the effect of shorter thread length in the grip produced about an 8 percent increase in ultimate load.

The effect of length of grip is illustrated by Figure 8. Since the two grips involved are 4-1/8 in. and 8-1/4 in., ideally it would be expected that the 9-1/2 in. bolt might elongate approximately twice as much as the 5-1/2 in. bolt for a given load, so long as the shank and the thread regions remained in the elastic range. A ratio of the elongations at proof load shows the actual ratio to be 1.88 for the 1/8 in. thread in the grip (and about 1.84 for the 9/16 in. thread in the grip although some plastic behavior had begun and this comparative plot is not shown). It seems reasonable that a ratio of less than 2.0 would actually result since the length of thread in the grip (or the length with reduced cross-sectional area) makes up a larger percentage of the total grip for the shorter bolt, so that, relatively, a greater elongation might be expected in the short bolts.

In connection with the direct tension testing summarized in Table 1 and shown in Figures 2 through 8, it was noted that all direct tension specimens except one, a 9-1/2 in. bolt with 9/16 in. thread in the grip, reached the specified minimum ultimate load of 69.3 kips, even though there were four thread stripping failures (in the 5-1/2 in. group). The measurements, prior to testing, of the bolt and nut thread diameters of those stripped 5-1/2 in. bolt specimens are shown below along with the appropriate ASA tolerances for a Class 2 fit (ASA B1.1-1949):

| | Average Measured Thread Diameter, In. | ASA Class 2 Tolerance, In. | |
|---|---|---|---|
| | | Min. | Max. |
| 7/8 in. x 5-1/2 in. Bolts | 0.863 | 0.859 | 0.873 |
| 7/8 in. x 9-1/2 in. Bolts | 0.860 | 0.859 | 0.873 |
| 7/8 in. Heavy Nuts | 0.773 | 0.755 | 0.778 |

The actual, "as measured" thread dimensions shown above give a relatively "loose" fit of nut and bolt. Although thread measurements were not made for any of the 9-1/2 in. specimens which were tested (since no stripping occurred), a subsequent examination of several bolts showed the average diameter to be 0.860 in., actually slightly less than the diameters measured on the shorter bolts. However, it should be recalled that the threads of the 9-1/2 in. bolts apparently were cut or machined after the heat-treating operations, while it appeared that the rolling of the 5-1/2 in. bolt threads had been done before heat-treating. Six out of a total of eight stripping failures under direct and torqued tension testing occurred in bolts with 1/8 in. thread in the grip, apparently because of the higher loads which were developed.

## 11. Load-Rotation Relationships

Load vs. rotation data are plotted in Figures 9 through 13. Several results of interest appear in a study of Figure 9: (1) Upon tightening the shorter A490 bolts in a solid block, proof load was reached in just over 1/4 turn from a "snug" of 10 kips. (2) The comparable results from Ref. 4 agree remarkably with the data of the solid block tests reported herein. (3) All but one of the 5-1/2 in. bolts tested at Illinois reached proof load at 1/2 turn in the calibrator, but the hydraulic calibrator is obviously much "softer" than a solid block. (4) There appears to be some variation in that "softness" between the calibrator used at Illinois and that used at Lehigh, based on the average curve shown.

When more threads are included in the grip, slightly more turns of the nut are required to reach proof load. This can be seen by comparing Figures 9 and 10. In Figure 10 it will be noted that only two of five 5-1/2 in. bolts with 9/16 in. thread in the grip torqued in the calibrator reached the proof load at 1/2 turn from "snug." Also, the "softer" calibrator used for the tests of Ref. 4 gave an average of about 1/8 turn more to reach proof load than was required by the calibrator used by Illinois.

The effects of thread length in the grip (for the 5-1/2 in. bolt tests reported herein) are best portrayed in Figure 11. The difference produced by the variations of almost 1/2 in. or four threads in the grip is small when compared to the difference in the effect produced by a solid block in the grip and by a hydraulic calibrator. Actually, a multiple-ply structural joint might be expected to fall somewhere between these two extremes, depending on the thoroughness with which the steel has been drawn up during the snugging and assembly operations; the number, thickness, and flatness of the plies; etc.

In Figure 12, the data from the 9-1/2 in. long bolt tests again show very little effect from the thread length in the grip until after proof load has been reached. The relative "softness" of the calibrator used in the tests of Ref. 4 is also again evident. The Illinois tests reached only an average of about 88 percent of proof load at 1/2 turn, or required about 0.61 to 0.67 turn to reach proof load. These tests were made in a hydraulic calibrator which, as mentioned above, may be thought to represent an upper limit on "softness" which might be expected in actual structural joints. It might also be pointed out that tests made with actual steel workers operating pneumatic wrenches have shown that "snug" often will be greater than the 10 kips used herein as a reasonable base from which to calculate turns. (These 9-1/2 in. bolts are almost 11 diameters long, or more than the 8 diameters length limit which may be recommended in the 1964 Council specification revision as the maximum length for which only "1/2 turn from snug" will be prescribed; bolts eight diameters or 8 in. long may be required to have "2/3 turn from snug").

The effects of bolt length and bolt grip on the load-rotation data for calibrations in a hydraulic load cell have been combined in Fig. 13.

Among the important data summarized in Table 2 are the ratios of torqued tension ultimates to direct tension ultimates. The Illinois tests varied from 82 to 88 percent and averaged 85 percent. These values compare well with the commonly presented value of 85 percent, the value of 82 percent mentioned in Ref. 2 for A354 BD bolts, the 83.5 percent in Ref. 4 for A490 bolts, and the 84 percent from the extensive tests of Ref. 5 with A325 bolts.

Since readings of actual bolt load could not be taken during the solid block tests, the load vs. rotation plots shown in Figures 9, 10 and 11 were obtained by applying the measured bolt elongations in the solid block tests to the average calibrator load vs. elongation curves and picking off the corresponding loads. It is assumed that the load vs. elongation relationship is constant regardless of the flexibility of the material in the grip.

The solid block curves are shown in these figures only up to the ultimate load since the scatter of actual load vs. elongation data beyond that point did not justify continuation.

It is felt that the data on load vs. rotation relationships for the solid block tests are most easily interpreted after the conversions mentioned in the paragraph above have been completed. However, a process of obtaining the data for Figures 9 through 13, for the 5-1/2 in. bolt tests, is demonstrated in Figures 14 and 15. The rotation vs. elongation curves are based on the left ordinate scale, while the load vs. elongation curves are obtained using the right ordinate scale. Once again the slightly "softer" response, of the hydraulic calibrator of Ref. 4 is apparent, especially in the elastic range. Because of the extensive scatter beyond the maximum bolt load, the average lines of Figures 14 and 15 cannot be considered useful beyond that point.

12. Description of Failures

All of the direct tensile tests which failed in the bolt did so at, or near, the face of the nut. The 9-1/2 in. bolts with 1/8 in. thread in the grip appeared to have a more ductile type of failure than the 5-1/2 in. bolts with short thread, probably due in part to the differences in method of thread manufacture for the two lengths. Considerable necking of the threads was noted in the direct tensile tests with 9/16 in. thread in the grip. Although the failure planes in these bolts occurred some distance from the thread runout, visible cracks were observed in the bolt threads remaining between the failure surface and thread runout. Most of these fracture planes were inclined and occurred over several threads.

All of the torqued tension tests conducted in the Skidmore-Wilhelm calibrator also failed near the nut face and showed evidence of a combination of tension and torsional shear. The difference in thread length in the grip did not affect the appearance of the failures in these torqued tests as much as in the direct tension tests. The failure surfaces generally extended over two threads, and some contained a small longitudinal tear, probably indicating that the final failure occurred in tension. Some slight necking was observed in the tests with 9/16 in. thread in the grip.

The bolt failures obtained from torquing in the solid steel block were similar in appearance to those obtained in the calibrator. Five of those solid block tests, however, failed by stripping of the threads. It was noted that all of the direct tension and torqued tension specimens with 1/8 in. thread in the grip which developed tensile failures fractured right at the beginning of the minimum root diameter.

It might be noted that despite the differences in behavior for variations in the grip shown in this and earlier sections, the average number of turns to failure from "snug" appeared to be only slightly affected by the number of threads in the grip; this difference amounted to approximately one quarter turn more to failure for the longer-thread-in-grip bolts. In this same connection, from Table 2 it can be seen that, for the tests performed in the solid block, the average turns to failure were only about 6 percent less than for those similar tests performed in the hydraulic calibrator.

## IV. SUMMARY AND CONCLUSIONS

All data for this series of tests have been summarized in Tables 1 and 2 so that there is no need to repeat average figures here. A study of those tables and the figures will provide details not covered below. Based on the tests of A490 7/8 in. diameter bolts reported herein, the following conclusions appear justified:

1. Bolts tested in torqued tension attained ultimate loads which were approximately 85 percent of those reached in direct tension.

2. Bolts tested in direct tension with 1/8 in. thread in the grip had higher (by approx. 8 percent) ultimate strengths but less total elongation than did the 9/16 in. thread-in-grip bolts. When tested in torqued tension, these short thread-in-grip bolts had approximately one-quarter fewer turns to failure from snug than comparable bolts with 9/16 in. thread in the grip.

3. The difference in tightening a bolt in a solid block and in a relatively "soft" or "flexible" hydraulic calibrator may be substantial. In these tests the bolts torqued in the solid block reached proof load in just over 1/4 turn from "snug" while those in the calibrator required 1/2 turn or more from the same starting point (Fig. 11).

4. There appears to be some variation in "softness" or flexibility from one hydraulic calibrator to another.

5. Long grip bolts will require more than 1/2 turn from a "snug" of 10 kips to insure proof load in a "soft" joint assembly. The calibrator tests for bolts eleven diameters long showed approximately 2/3 turn from "snug" to proof load.

6. The individual testing procedures employed in parallel investigations at two university laboratories did not produce significant variation in the test data obtained.

## REFERENCES CITED

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(5) J. G. Viner, E. Chesson, Jr., R. L. Dineen and W. H. Munse, "A Study of Nuts for Use with High-Strength Bolts," Structural Research Series No. 212, University of Illinois, March 1960.

TABLE 1

DIRECT TENSION CALIBRATION

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Bolt Diameter | in. | 7/8 | | | | 7/8 | | | |
| Bolt Length | in. | 5 1/2 | | | | 9 1/2 | | | |
| Thread Length | in. | 1 1/2 | | | | 1 1/2 | | | |
| Spec. Proof Load | kips | 55.45 | | | | 55.45 | | | |
| Spec. Min. Ult. Load | kips | 69.3 | | | | 69.3 | | | |
| Testing Agency | | ILLINOIS | LEHIGH | ILLINOIS | LEHIGH | ILLINOIS | LEHIGH | ILLINOIS | LEHIGH |
| Nominal Grip | in. | 4 1/8 | (4 1/8) | 4 9/16 | (4 9/16) | 8 1/4 | (8 1/4) | 8 11/16 | (8 5/8) |
| Thread Length in Grip | in. | 1/8 | (1/8) | 9/16 | (9/16) | 1/8 | (1/8) | 9/16 | (9/16) |
| No. of Specimens Tested | | 5 | (5) | 5 | (5) | 6 | (5) | 5 | (5) |
| Mean Ult. Load | kips | 75.9 | (76.0) | 72.1 | (72.1) | 74.6 | (73.2) | 69.8 | (70.8) |
| Standard Deviation | kips | 0.45 | (0.54) | 0.54 | (0.17) | 1.57 | (1.59) | 1.32 | (1.69) |
| % Spec. Min. Ult. Load | | 109 | (110) | 104 | (104) | 108 | (106) | 101 | (102) |
| Mean Elong. at Ult. Load | in. | .047 | (.0508) | .0569 | (.0647) | .0710 | (.0779) | .0792 | (.0846) |
| Mean Rupture Load | kips | 68 | (67) | 61 | (59) | 67 | (65) | 62 | (61) |
| Mean Elong. at Rupture | in. | - | (0.137) | - | (0.245) | - | (0.12) | - | (0.18) |
| Mean Elong. after Rupture | in. | 0.13 | - | 0.23 | - | 0.15 | - | 0.19 | - |
| Mean Elong. at Proof Load | in. | .0147 | (.0154) | .0160 | (.0171) | .0280 | (.0282) | .0297 | (.0292) |
| No. of Bolt Tensile Failures | | 2 | - | 4 | - | 5 | - | 5 | - |
| No. of Stripping Failures | | 3 | - | 1 | - | 0 | - | 0 | - |

TABLE 2 TORQUED TENSION CALIBRATION

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Bolt Diameter | in. | 7/8 | | | | 7/8 | | | |
| Bolt Length | in. | 5 1/2 | | | | 9 1/2 | | | |
| | | Torqued in Skidmore-Wilhelm | | | | Torqued in Skidmore-Wilhelm | | | |
| Testing Agency | | ILLINOIS | LEHIGH | ILLINOIS | LEHIGH | ILLINOIS | LEHIGH | ILLINOIS | LEHIGH |
| Nominal Grip | in. | 4 1/8 | (4 1/8) | 4 9/16 | (4 9/16) | 8 1/4 | (8 1/4) | 8 11/16 | (8 5/8) |
| Thread Length in Grip | in. | 1/8 | (1/8) | 9/16 | (9/16) | 1/8 | (1/8) | 9/16 | (9/16) |
| No. of Specimens Tested | | 5 | (5) | 5 | (5) | 5 | (5) | 5 | (5) |
| Mean Load at 1/2 Turn from "Snug" | kips | 56.4 | (53.4) | 54.3 | (50.0) | 48.4 | (48.8) | 47.6 | (41.1) |
| Mean Ult. Load | kips | 62.3 | (61.1) | 60.1 | (58.4) | 65.4 | (65.4) | 60.1 | (61.8) |
| Standard Deviation | kips | 3.11 | (2.80) | 2.63 | (3.00) | 3.47 | (2.80) | 0.55 | (2.18) |
| Mean Rupture Load | kips | - | (40) | - | (34) | - | (52) | - | (50) |
| Mean Elong. at Ult. Load | in. | .0249 | (.0260) | .0372 | (.0310) | .0566 | (.0525) | .0598 | (.0698) |
| Mean Elong. after Rupture | in. | 0.09 | (0.075) | 0.15 | (0.11) | 0.11 | (0.08) | 0.13 | (0.114) |
| Mean Elong. @ Proof Load | in. | .015 | (.016) | .018 | (.018) | .028 | (.028) | .033 | (.031) |
| Ave. Turns to "Snug" from Finger Tight | | 0.32 | - | 0.29 | - | 0.31 | - | 0.31 | - |
| Ave. Turns to Proof Load from "Snug" | | 0.48 | - | 0.52 | - | 0.61 | - | 0.67 | - |
| Ave. Turns to Failure from "Snug" | | 1.34 | (1.25) | 1.61 | (1.56) | 1.45 | (1.37) | 1.59 | (1.87) |
| Ratio, $\frac{\text{(Torqued Tension Ult.)}}{\text{(Direct Tension Ult.)}}$ | | 0.82 | (0.80) | 0.83 | (0.77) | 0.88 | (0.90) | 0.86 | (0.87) |
| | | Torqued in Solid Block | | | | | | | |
| No. of Bolt Tensile Failures | | 2 | - | 4 | - | | | | |
| No. of Stripping Failures | | 3 | - | 1 | - | | | | |
| Mean Elong. after Rupture | in. | 0.09 | - | 0.15 | - | | | | |
| Ave. Turns to "Snug" from Finger Tight | | 0.16 | - | 0.26 | - | | | | |
| Ave. Turns to Proof Load from "Snug" | | 0.28 | - | 0.33 | - | | | | |
| Ave. Turns to Failure from "Snug" | | 1.26 | - | 1.50 | - | | | | |

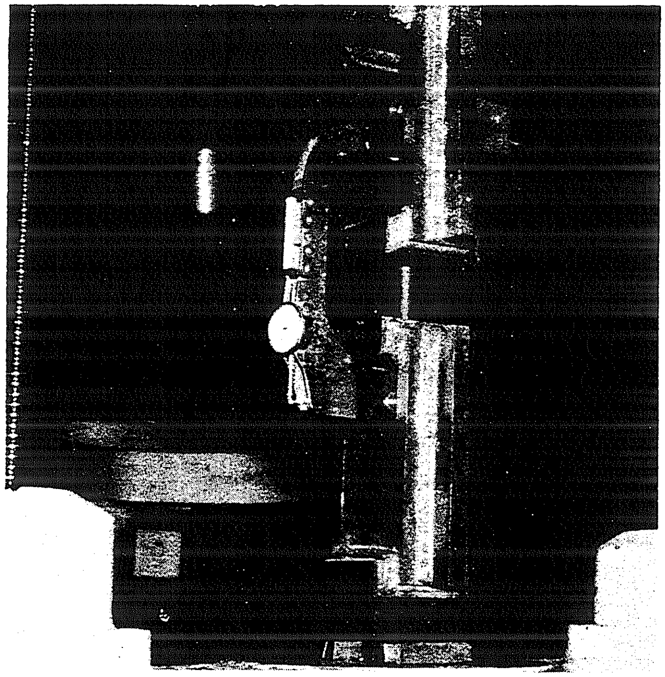

Fig. 1a  Direct Tension Specimen

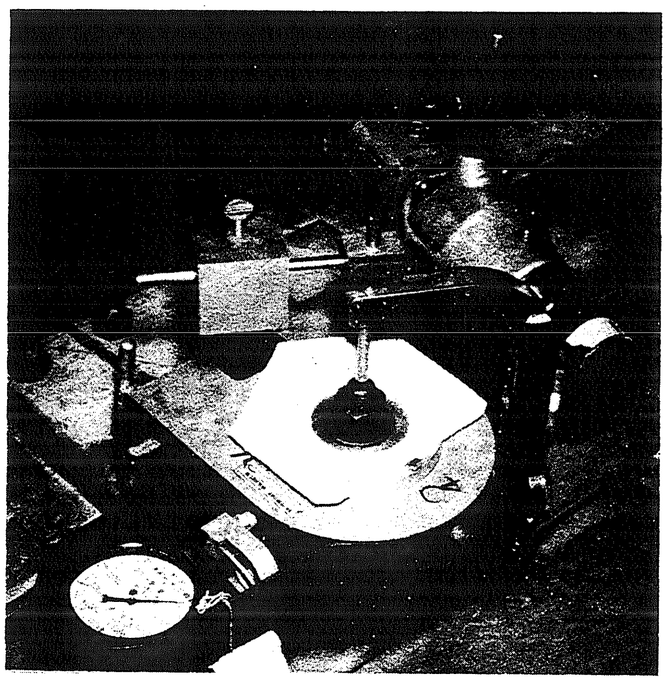

Fig. 1b  Torqued Tension Specimen in Skidmore-Wilhelm Calibrator

FIG. 1  SET-UP OF CALIBRATION TESTS

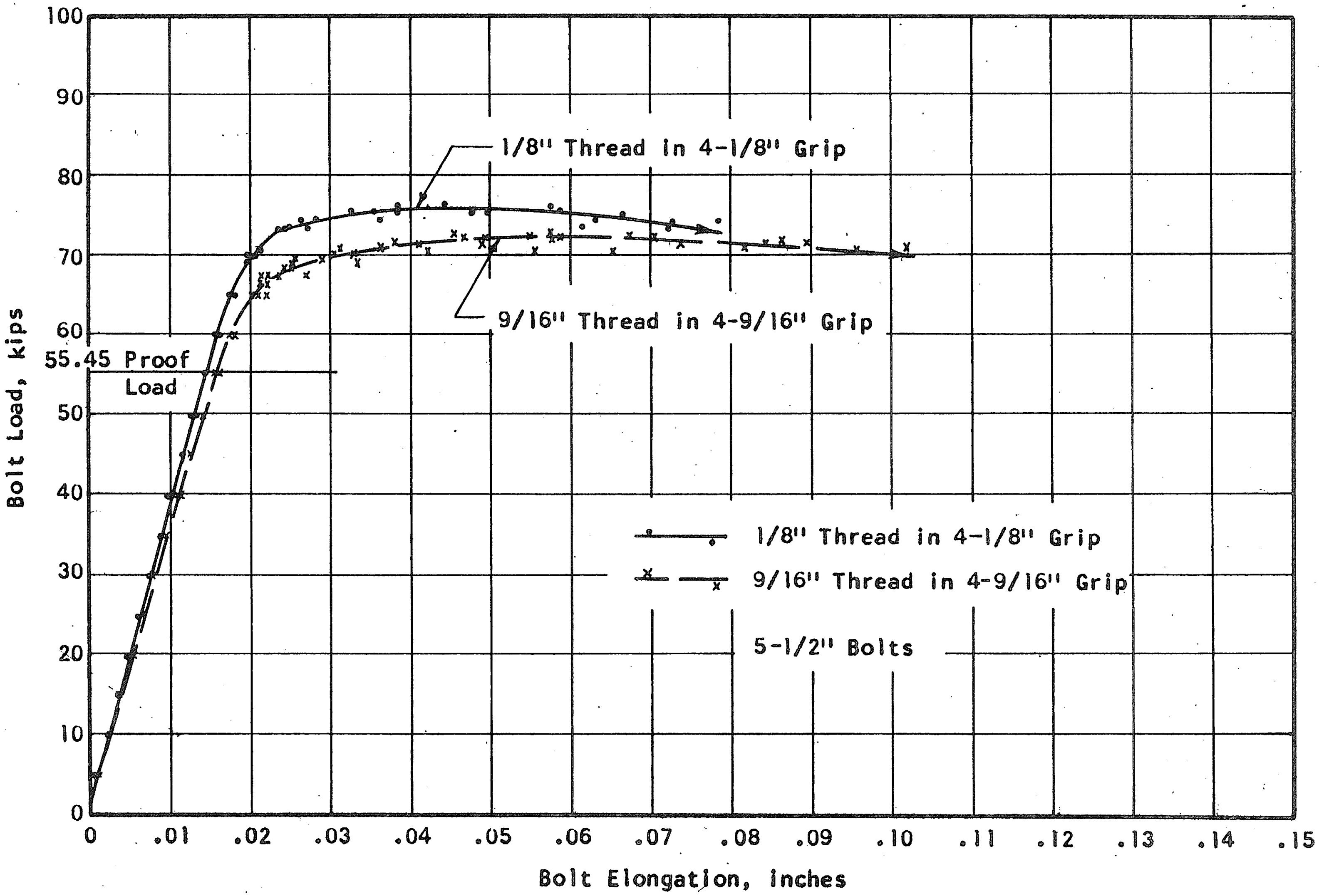


FIG. 2 DIRECT TENSION-ELONGATION RELATIONSHIPS OF 7/8"φ x 5-1/2" A490 BOLTS

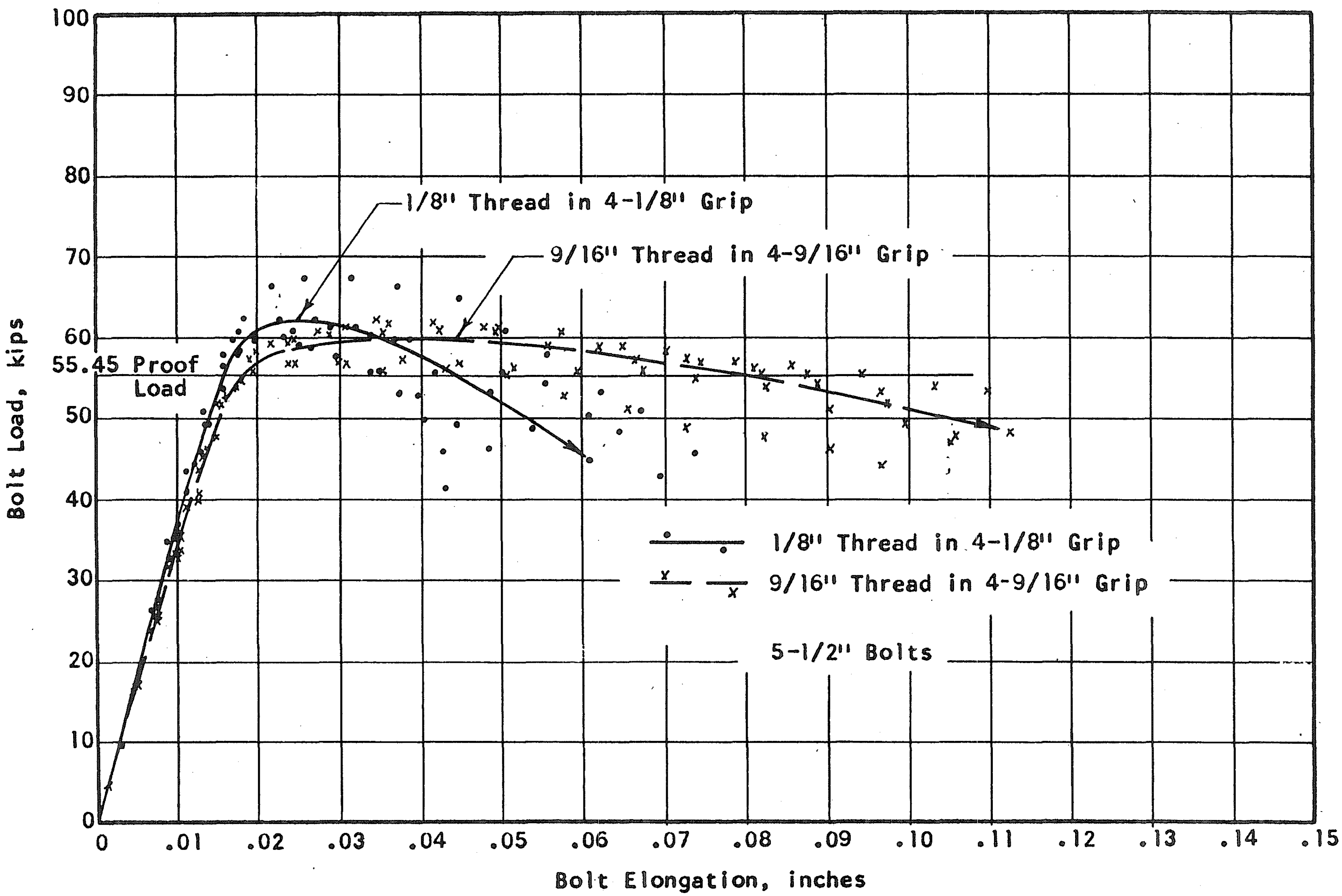


FIG. 3 TORQUED TENSION - ELONGATION RELATIONSHIPS FOR 7/8"φ x 5-1/2" A490 BOLTS TORQUED IN SKIDMORE-WILHELM CALIBRATOR

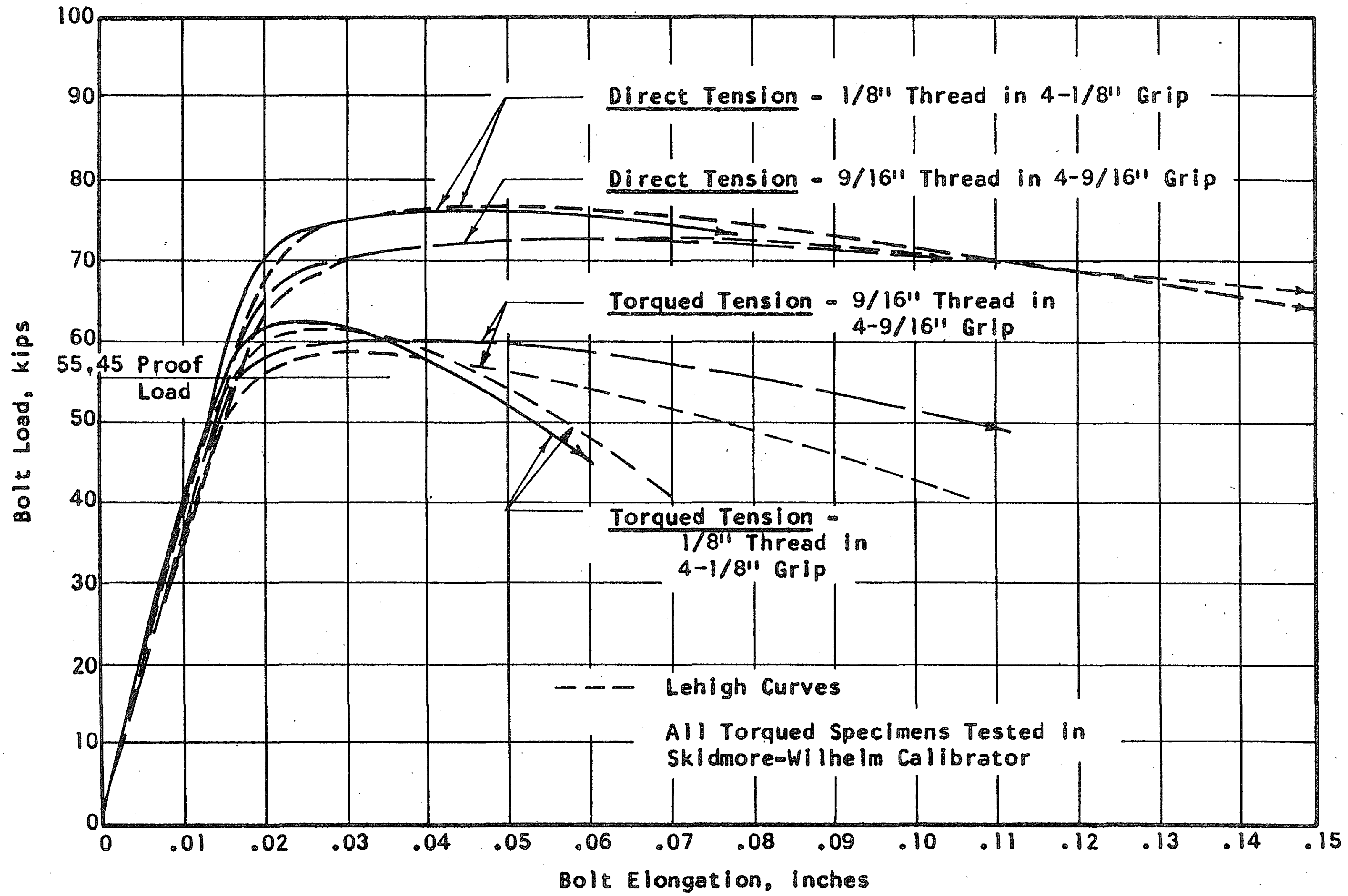


FIG. 4 EFFECT OF METHOD OF LOADING ON TESTS OF 5-1/2" A490 BOLTS

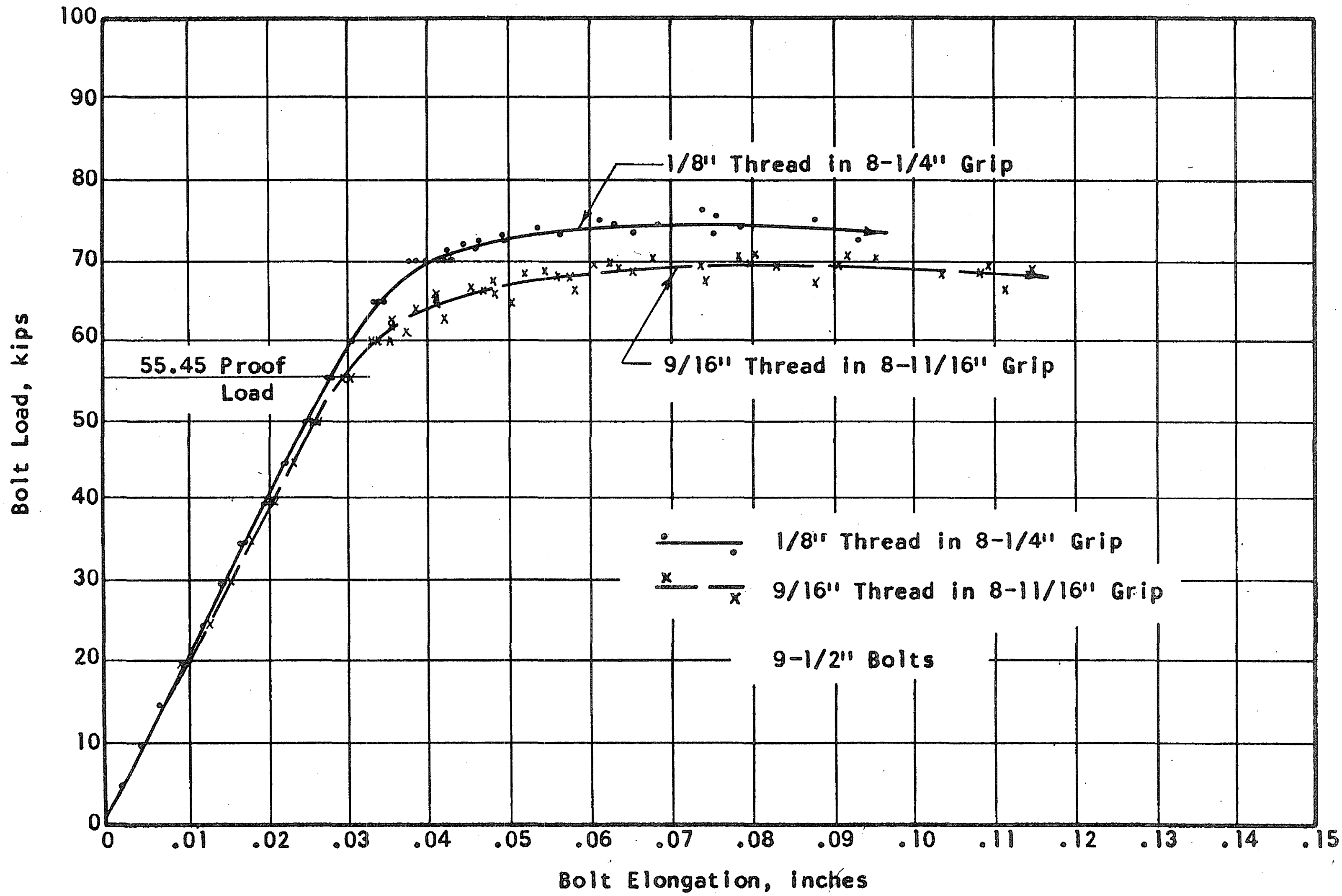


FIG. 5 DIRECT TENSION-ELONGATION RELATIONSHIPS OF 7/8"φ x 9-1/2" A490 BOLTS

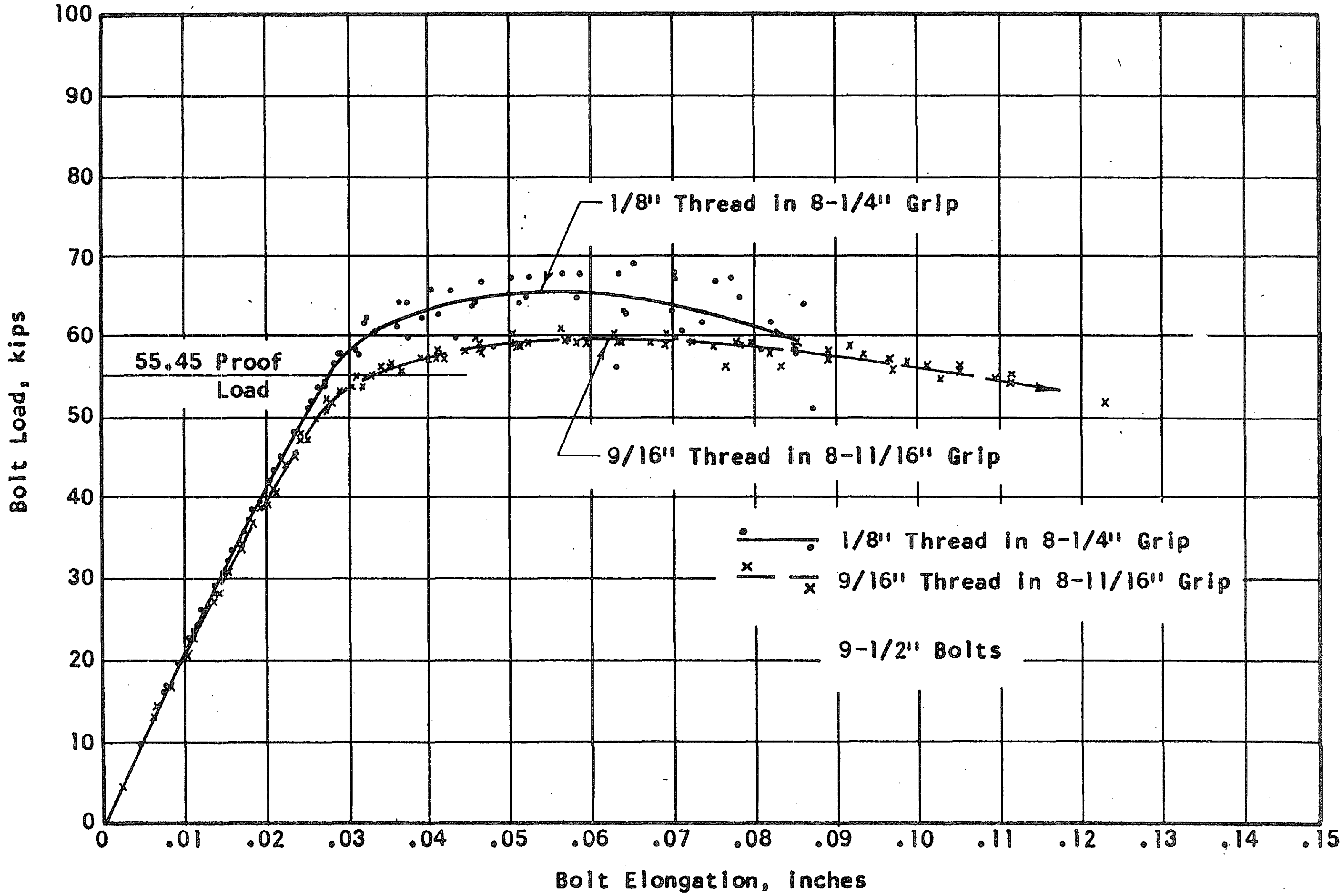


FIG. 6 TORQUED TENSION-ELONGATION RELATIONSHIPS OF 7/8"φ x 9-1/2" A490 BOLTS TORQUED IN SKIDMORE-WILHELM CALIBRATOR

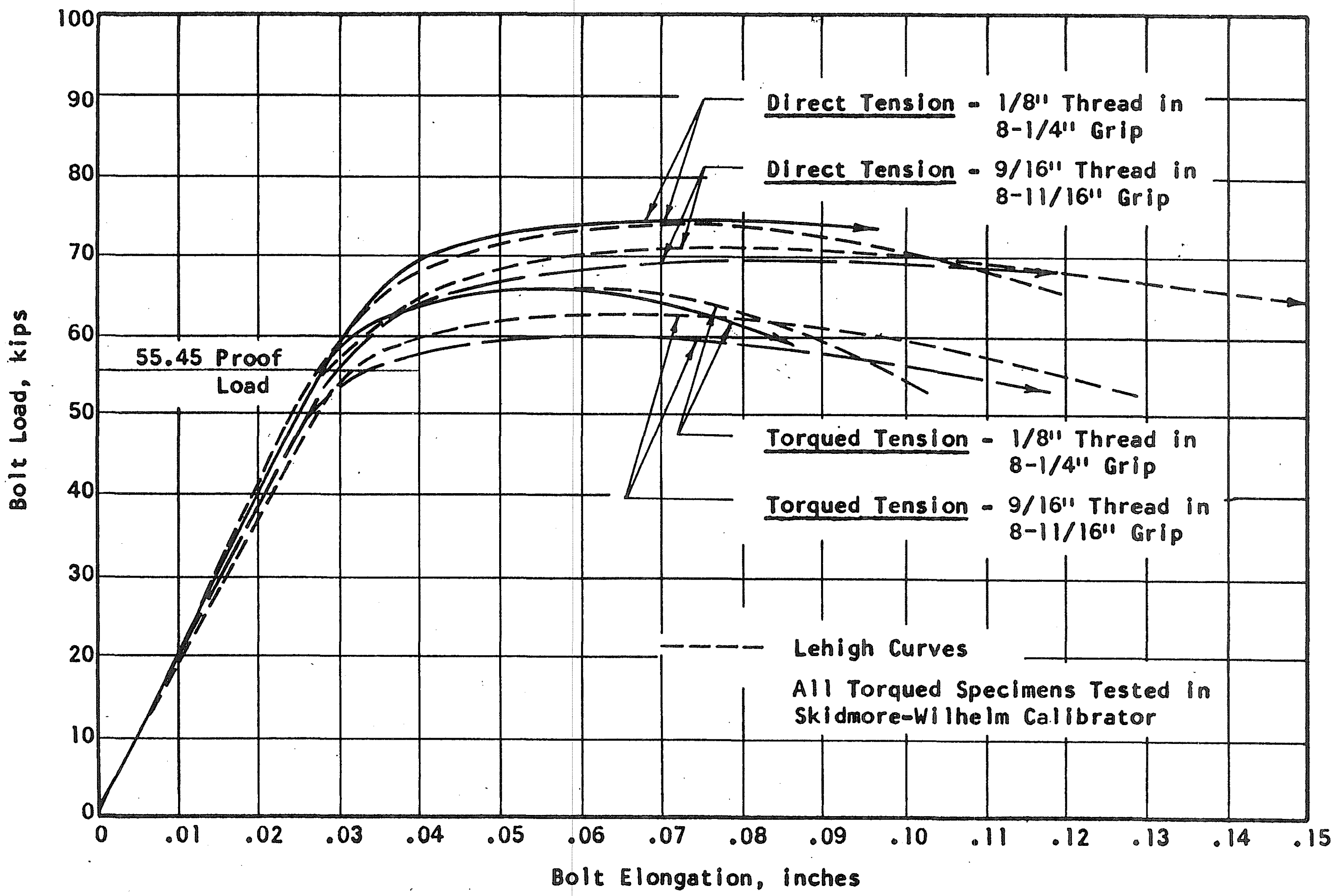


FIG. 7 EFFECT OF METHOD OF LOADING ON TESTS OF 9-1/2" A490 BOLTS

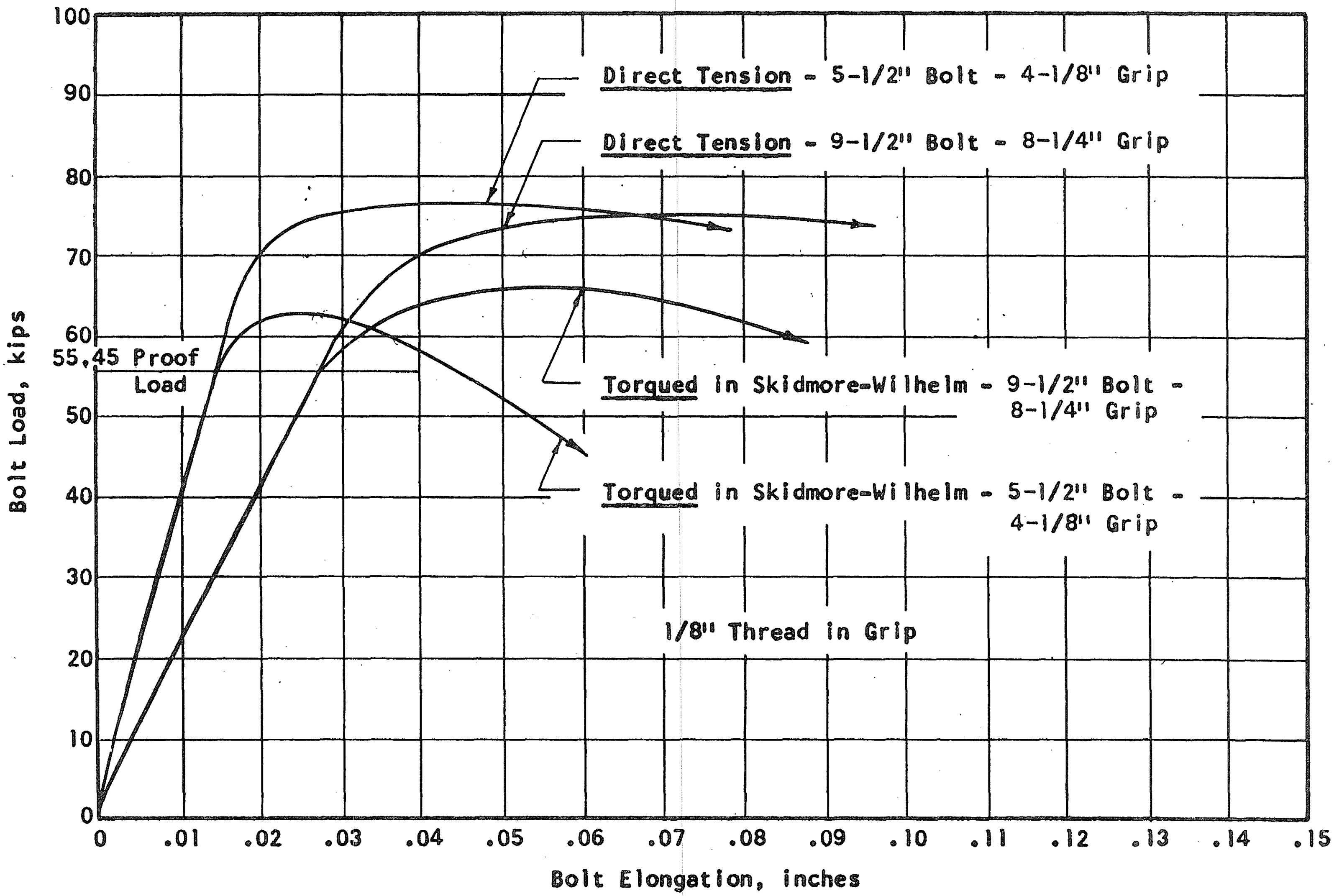


FIG. 8 EFFECT OF GRIP ON DIRECT AND TORQUED TENSION TESTS WITH 1/8" THREAD IN GRIP

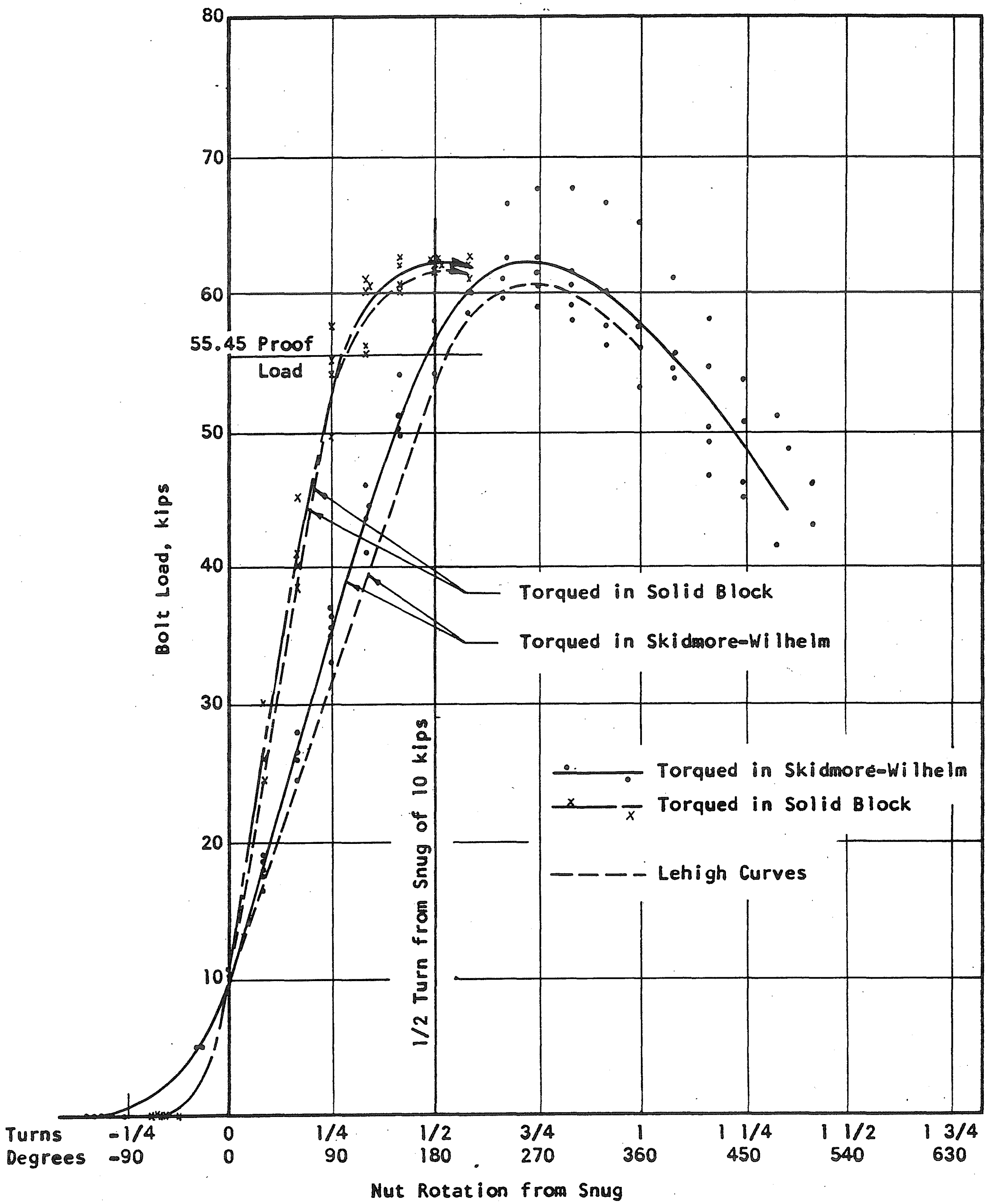


FIG. 9 TORQUED TENSION-ROTATION RELATIONSHIPS OF 7/8"φ x 5-1/2" A490 BOLTS WITH 1/8" THREAD IN 4-1/8" GRIP

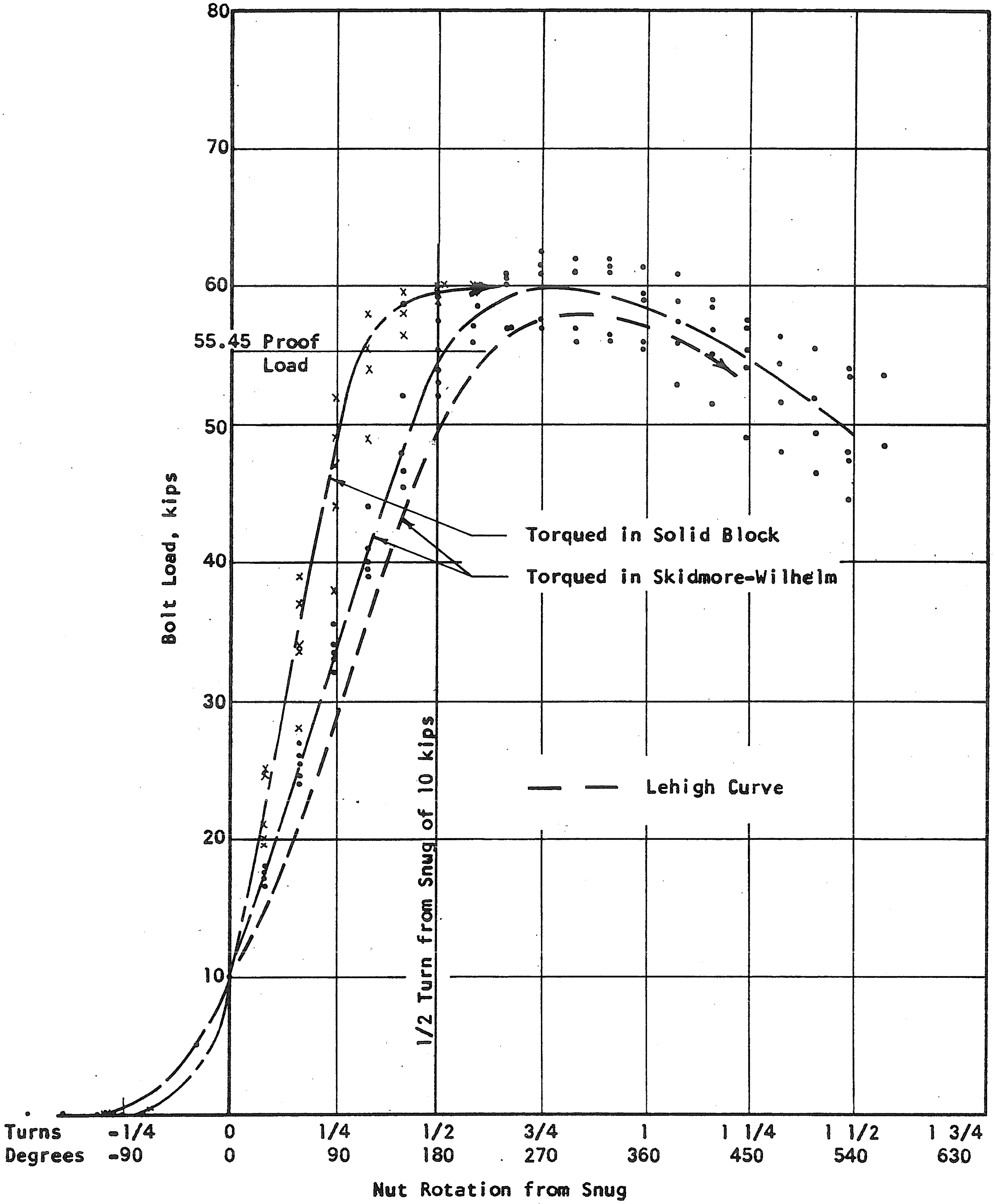


FIG. 10 TORQUED TENSION-ROTATION RELATIONSHIPS OF 7/8"φ x 5-1/2" A490 BOLTS WITH 9/16" THREAD IN 4-9/16" GRIP

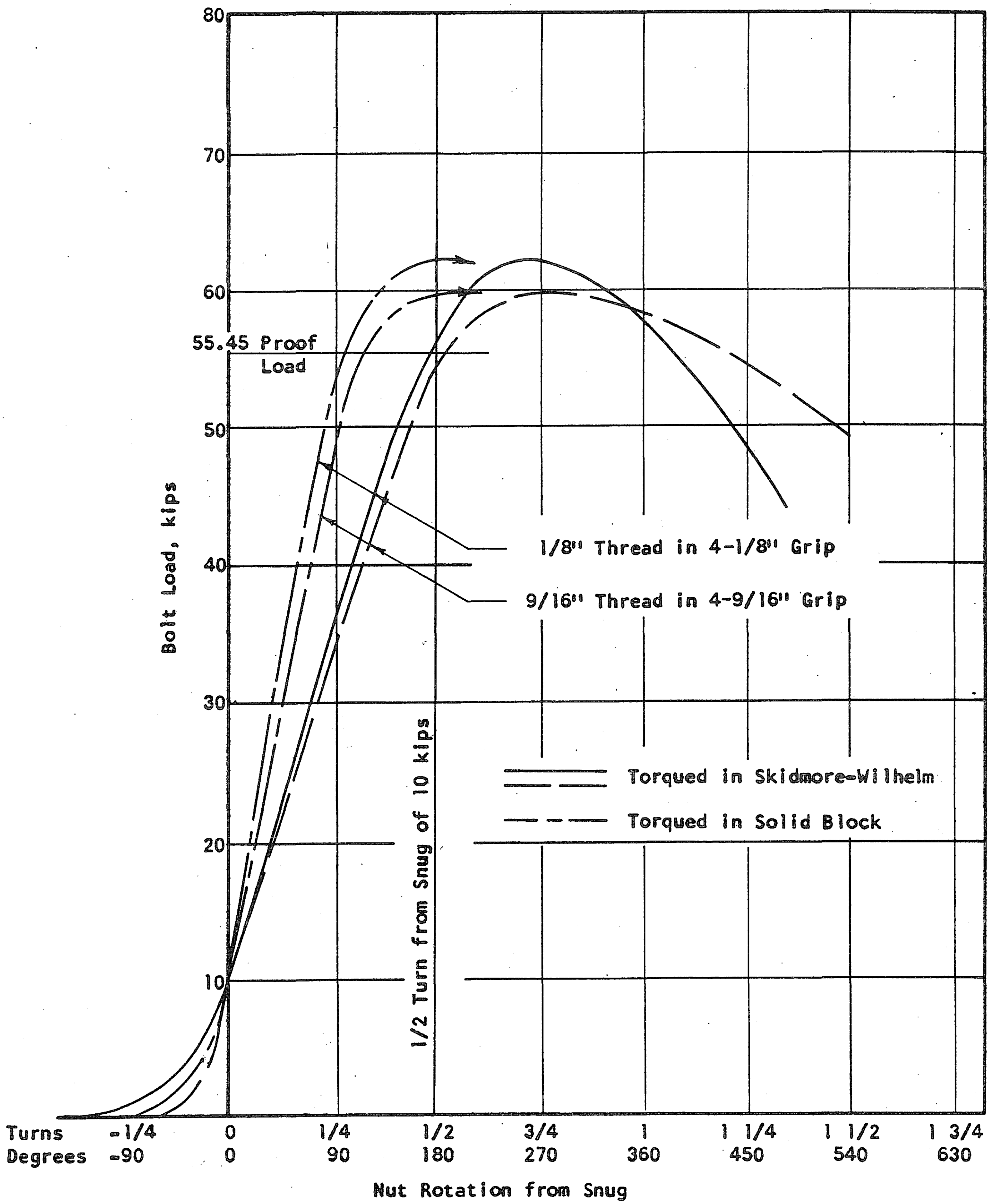


FIG. 11 EFFECT OF TORQUING 5-1/2" A490 BOLTS IN SKIDMORE-WILHELM AND IN SOLID BLOCK

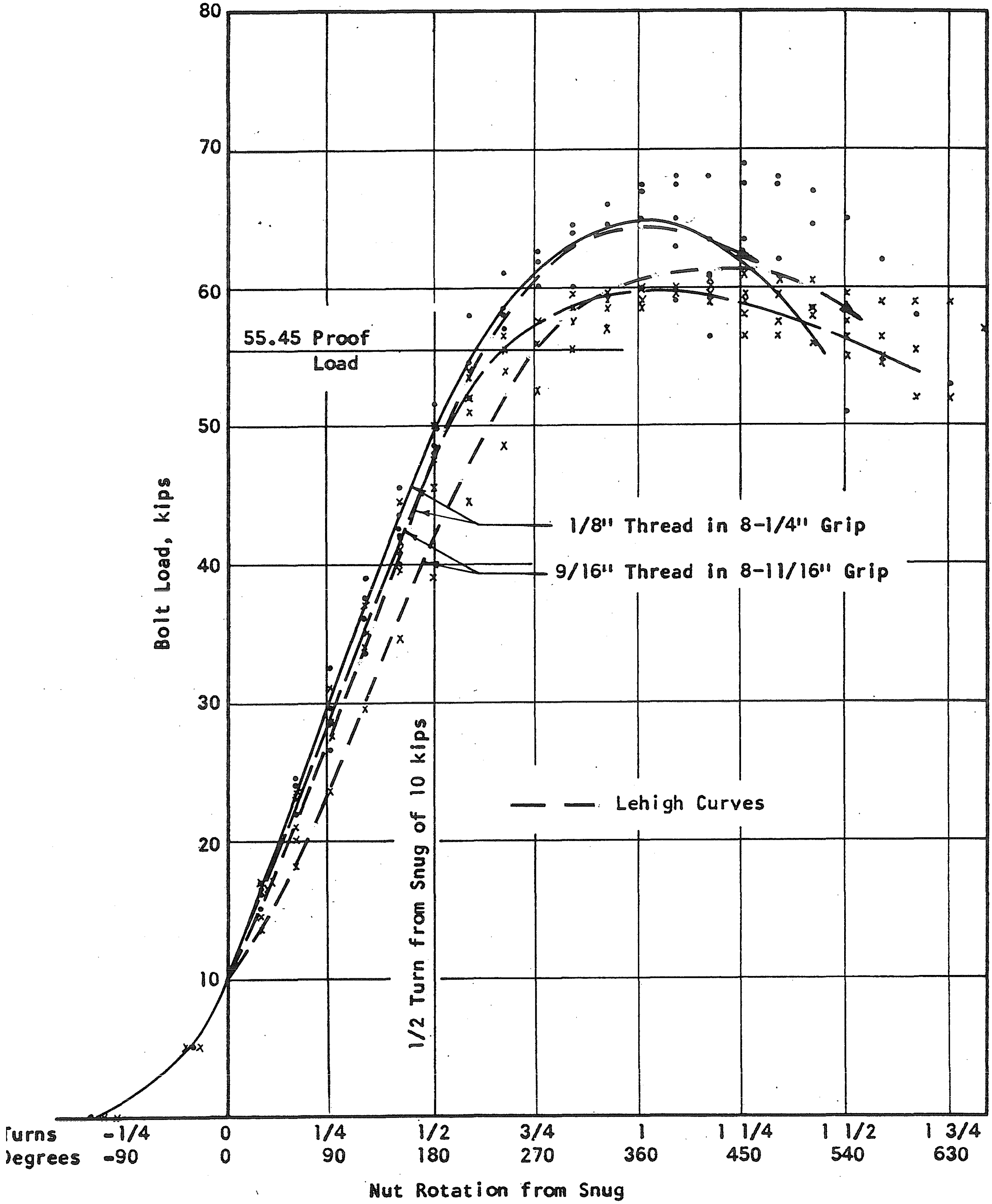


FIG. 12 TORQUED TENSION-ROTATION RELATIONSHIPS OF 7/8"φ x 9-1/2" A490 BOLTS TORQUED IN SKIDMORE-WILHELM CALIBRATOR

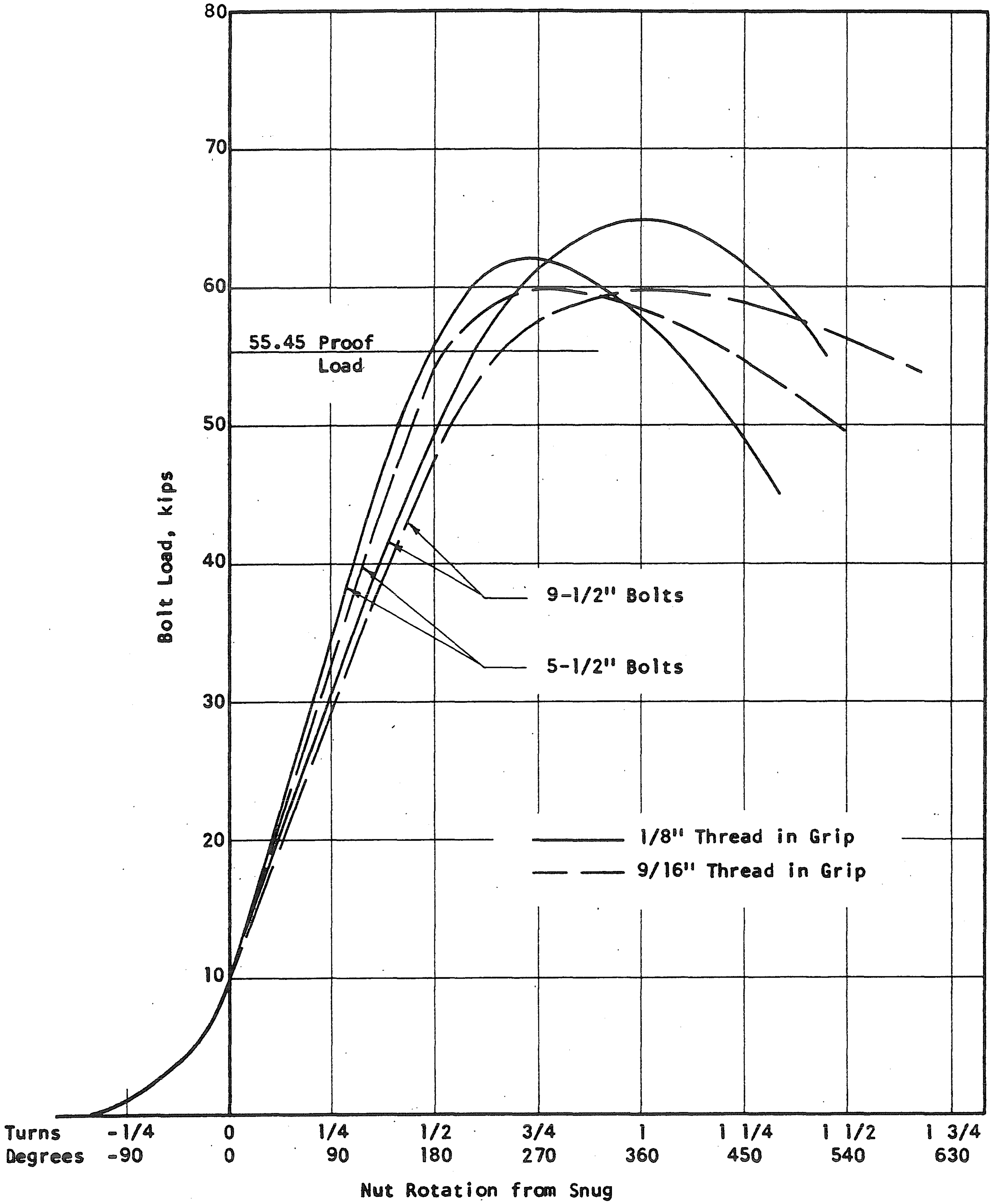


FIG. 13 TORQUED TENSION-ROTATION RELATIONSHIPS OF 5-1/2" AND 9-1/2" BOLTS TORQUED IN SKIDMORE-WILHELM CALIBRATOR

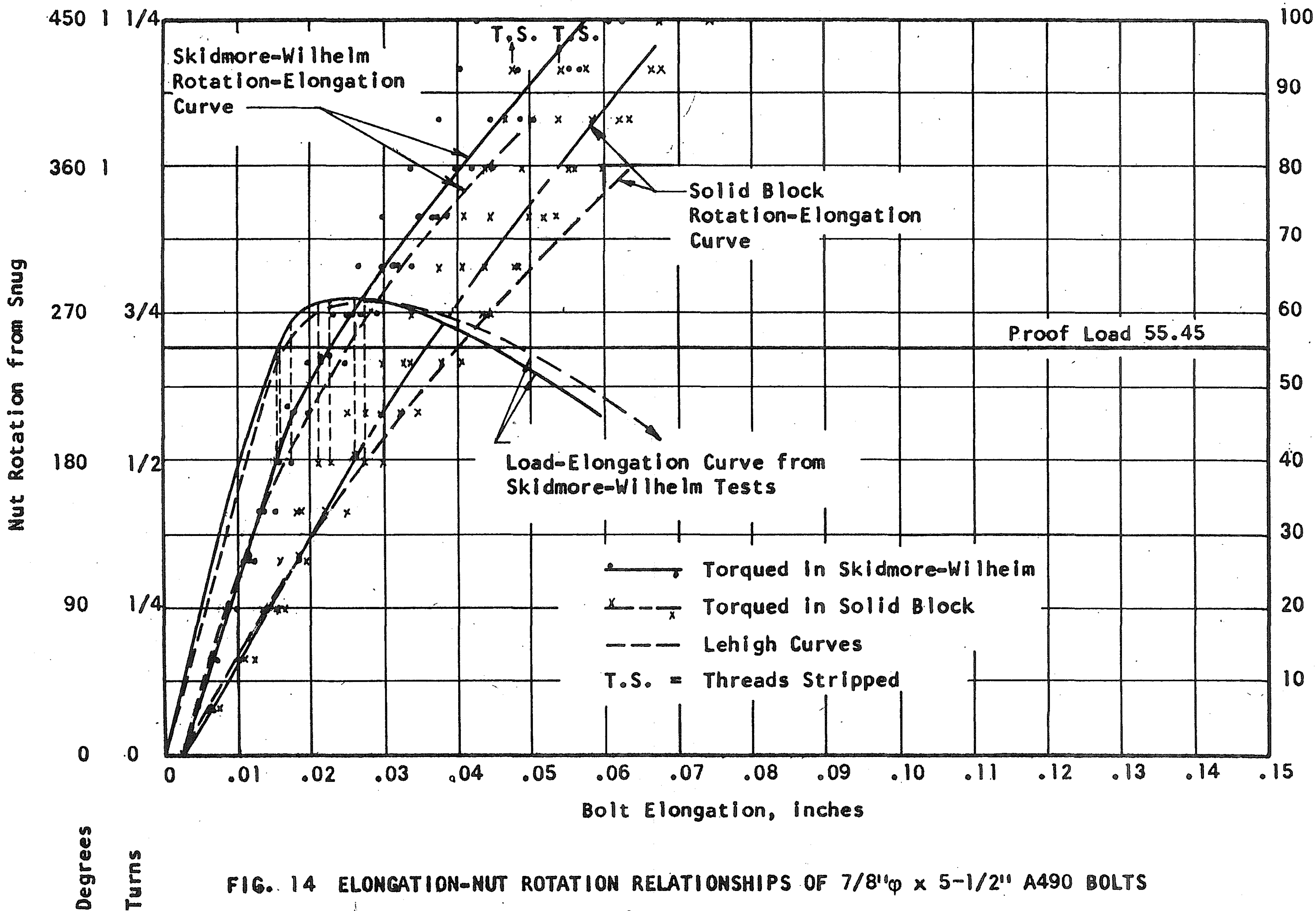


FIG. 14 ELONGATION-NUT ROTATION RELATIONSHIPS OF 7/8"φ x 5-1/2" A490 BOLTS WITH 1/8" THREAD IN 4-1/8" GRIP

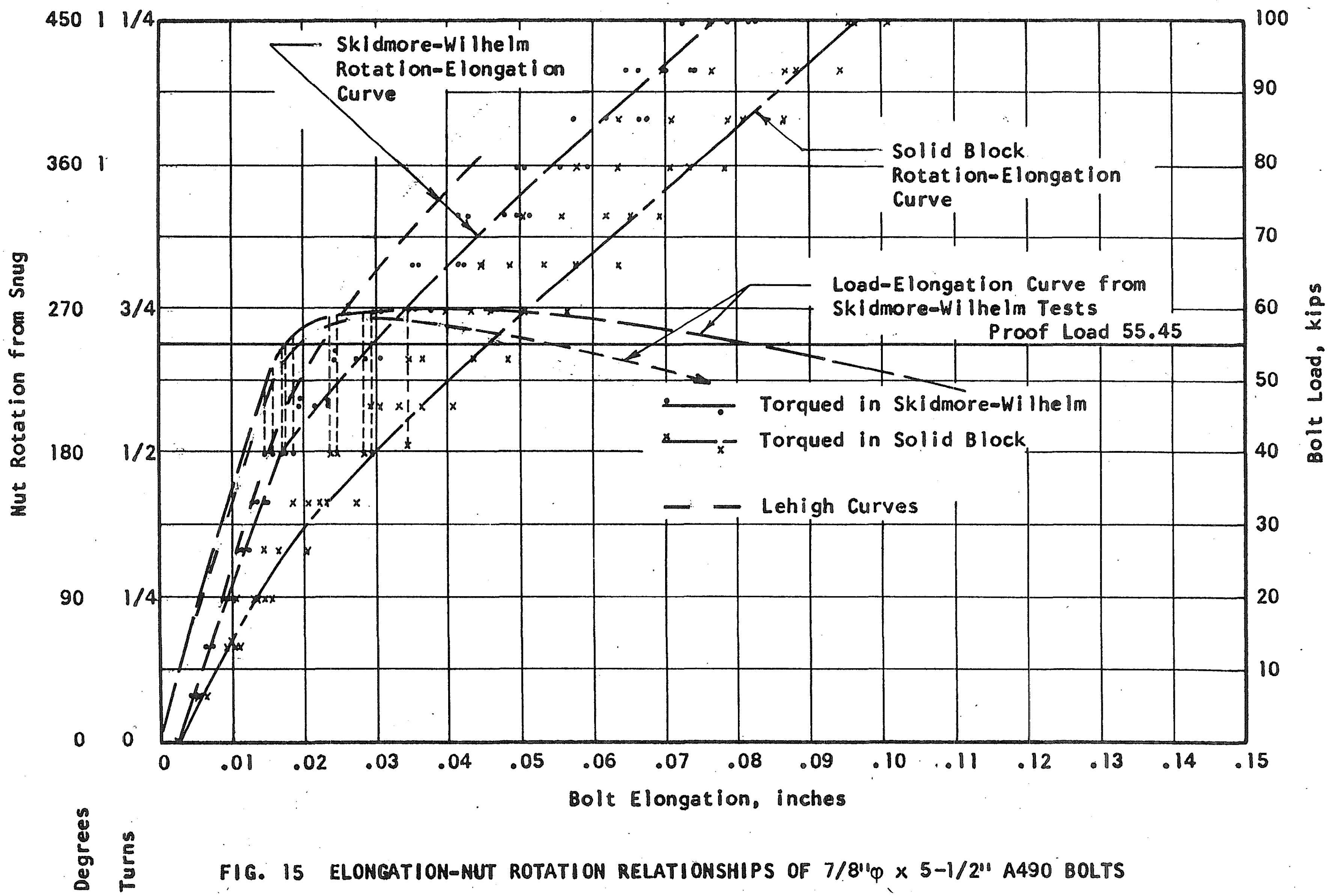


FIG. 15 ELONGATION-NUT ROTATION RELATIONSHIPS OF 7/8"φ x 5-1/2" A490 BOLTS WITH 9/16" THREAD IN 4-9/16" GRIP